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A REFINED METHOD FOR ESTIMATING OPTICAL DISTORTIONS IN HARDENED GLASS

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A new method for predicting optical distortions in hardened glass is proposed, which refines the earlier proposed dependences. The nonlinear dependence of the elasticity modulus on the glass temperature is taken into account.

The advanced method for horizontal hardening of sheet glass despite all positive features has a significant drawback: as heated glass is transported over rigid supports constituting a roll conveyor, deformations in the form of waves or the front edge flange emerge and become fixed in the glass article.

According to the model by N. V. Solomin [1], the current deformation (fold) in time τ is determined as follows:

$$y(\tau) = \omega S,$$

where ω is the elastic deformation for the preset bearing conditions of the article; S is the modulus of transition to inelastic deformation.

The parameter ω in flanging was determined earlier [2]:

$$\omega = \frac{ql^4}{4EI},$$

where q is the specific gravity load; l is the space between the roll conveyor supports; E is the elasticity modulus of the material under normal conditions; I is the axial inertia moment of the beam cross-section.

According to N. V. Solomin [1]:

$$S = \frac{G\tau}{\eta(t)};$$

$$G = \frac{E}{2(1+\mu)},$$

where G is the shear modulus; $\eta(t)$ is the viscosity as the function of temperature; μ is the Poisson coefficient.

The dependence of glass viscosity on temperature is implied in the specified relationships, whereas with respect to the elasticity modulus, the question remains open. At the same time, it is known [3] that the value $E(t)$ in the considered technological range varies by several orders of magnitude. The present study refines the method for calculating the deformation of hardened glass taking into account this indisputable factor.

The calculation used the earlier approved approximation [4] of the following form:

$$E(t) = a + \frac{b}{\left(1+\exp\left(-\frac{t-c}{14.42}\right)\right)^{0.32}}.$$

Thus, the extended expression for determining current deformation is as follows:

$$y(\tau) = \frac{1}{2}\frac{E(t)\,l}{(1+\mu)\,\eta(t)\,v}\,\omega.$$

Based on this relationship, the plots of the glass sag y depending on the velocity of the glass article motion v under

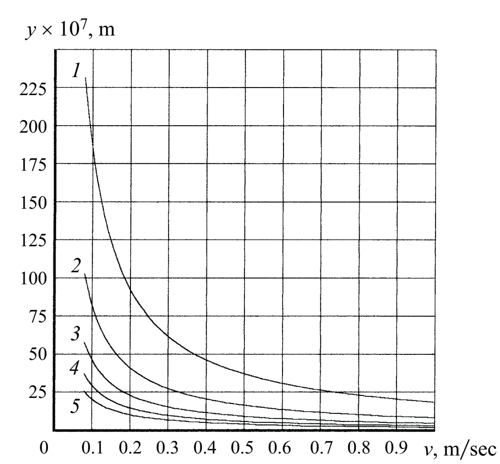

Fig. 1. Dependence of the glass sheet sag on its transportation velocity inside the furnace: *1*, *2*, *3*, *4*, and *5*) d = 2, 3, 4, 5, and 6 mm, respectively.

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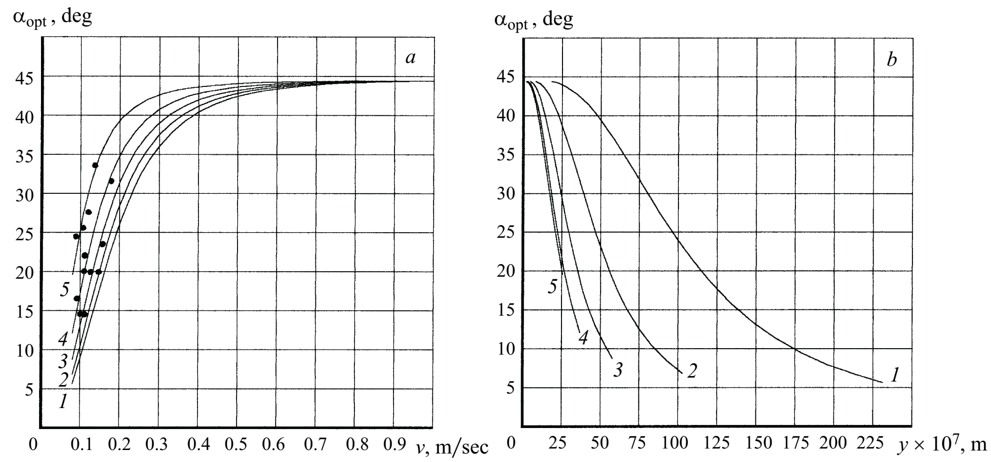

Fig. 2. Dependence of the optical properties of glass on its transportation velocity inside the furnace (a) and on its sag when transported in the furnace (b). Same designations as in Fig. 1.

the fixed values $t = 640°C$ and $l = 80$ mm were constructed for different thickness of glass (Fig. 1). A multiple increase in deformation was observed as the glass thickness and the velocity of article transport decreased, and the sharpest increase in y was registered at $v < 0.3$ m/sec and $d < 3$ mm.

The real manifestation of this deformation is the angle of optical distortion of the article α_{opt} determined according to GOST 5727–88 on a Zebra device.

The earlier determined relationship [5]

$$\alpha_{opt} = S_{opt}\, y^{-1}$$

presumably does not fully correspond to reality; therefore, additional experiments were carried out in the specified field.

Based on experimental data, we were able to approximate the dependence $\alpha_{opt} = f(v)$ for a fixed space between the rolls $l = 80$ mm:

$$\alpha_{opt} = \frac{1}{m - \dfrac{(e + kd)\ln v}{v^2}}.$$

The constants in this case were $m = 2.25 \times 10^{-2}$, $e = 5.51 \times 10^{-4}$, $k = -7.968 \times 10^{-5}$. The formula includes the sheet thickness d, which made it possible to plot a series of curves for predicting the optical properties of articles on varying the parameters d and v (Fig. 2a). Furthermore, the dependence of the optical distortion angle on the article sag value (Fig. 2b) was generalized. As the result, it was established that the earlier proposed relationship [5] is not fully justified. This concerns the curve segments adjacent to the segment $\alpha_{opt} = 40 - 45°$.

The proposed method refines the calculations and can be used in predicting the optical properties of glass produced by the horizontal method. At the same time, the results of predicting the absolute deformation of sheet glass transported on a roll conveyor of the glass-hardening line are refined, which will make it possible in the future to set more accurately the technological parameters for hardening.

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